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THE CFB SUMMERSIDE PROJECT
CANADIAN STATE-OF-THE-ART IN AFBC BOILERS

M.E.D. Taylor and F.D. Friedrich

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THE CBF SUMMERSIDE PROJECT
CANADIAN STATE-OF-THE-ART IN AFBC BOILERS

by

M.E.D. Taylor* and F.D. Friedrich**

ABSTRACT

The paper describes two approaches to the design of a heating plant which will demonstrate the combustion of coal in atmospheric fluidized-bed boilers. The designs were prepared in reponse to competitive tenders sought for the supply and installation of a heating plant to operate in conjunction with an existing steam plant at Canadian Forces Base Summerside, Prince Edward Island. One design was based on British technology and the other on North American technology.

The new plant will consist of two boilers, each with a generating capacity of 18 Mg/h of steam at 965 kPa. The design fuel is high-volatile bituminous coal containing approximately 20% ash and 5% sulphur. The performance of the boilers on inferior coals, and with wood chips as a supplementary fuel providing up to 30% of the heat input, will also be demonstrated. The design requirements call for overbed feeding of coal sized 50 mm x 0, special provisions to deal with wet and/or frozen coal, a 4.5 to 1 turn-down range, and limits on emissions of SO_2 and particulates.

The two boilers differ considerably. The British design incorporates a single combustion bed with three fluidizing zones, all situated in a refractory chamber beneath the radiant furnace of a normal watertube boiler. Immersed tubes with forced circulation of boiler water remove heat from the bed to stabilize the bed temperature. The coal and limestone are simultaneously fed directly over the three fluidizing zones, by watercooled screw conveyors.

With the American concept there are two separate beds. Both have peripheral waterwall cooling with a common water wall between them, and one also has immersed tubes within the bed. This design uses natural circulation throughout. Coal is fed to each bed by a spreader stoker while the limestone

is fed by a drop pipe into each bed at the end opposite from the coal spreader.

Detailed designs and firm price proposals were received in January 1981. After thorough assessment by the sponsoring government departments the decision was made to purchase North American design. Construction is now in progress with completion scheduled for December 1982.

Because of the design competition procedure adopted, two Canadian manufacturers have been brought to the point of being able to offer fluidized-bed boilers for burning low-grade coal.

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CONTENTS

		Page
ABSTRACT		i
1.0	INTRODUCTION	1
2.0	FLUIDIZED BED COMBUSTION	2
3.0	BASE HEATING REQUIREMENTS AND FUEL OPTIONS	3
4.0	EMR - DND REQUIREMENTS	4
5.0	DEVELOPMENT OF COMPETITIVE DESIGNS	7
6.0	FOSTER WHEELER LTD. PLANT DESIGN	9
	6.1 Plant Layout	9
	6.2 Materials Storage and Handling Systems	10
	6.2.1 Coal	10
	6.2.2 Wood Chips	11
	6.2.3 Limestone	11
	6.2.4 Ash Handling	12
	6.3 Plant Auxiliary Systems	12
	6.3.1 Steam and Condensate Systems	12
	6.3.2 Lighting-up Fuel System	13
	6.4 Electrical	13
7.0	FOSTER WHEELER BOILER SYSTEM	14
	7.1 Gas Path	14
	7.2 Boiler, Furnace and Pressure Parts	14
	7.3 Feed Systems for Coal, Wood and Limestone	16
	7.4 Carbon Recycle	16
	7.5 Bed Drain System	17
	7.6 Secondary Heat Recovery and Flue Gas Clean-up	17
	7.7 Bed Light-up System	18
8.0	FOSTER WHEELER CONTROLS AND INSTRUMENTATION SYSTEM	19
	8.1 Control Room	19
	8.2 Control Philosophy	19
	8.3 Fluidized-bed Boiler Controls	19
	8.4 Controls for Miscellaneous Equipment and Systems	21
	8.5 Materials Handling Systems	22

		Page
9.0	DOMINION BRIDGE-SULZER PLANT DESIGN	22
	9.1 Plant Layout	22
	9.2 Materials Storage and Handling Systems	23
	9.2.1 Coal	23
	9.2.2 Limestone	24
	9.2.3 Wood Chips	24
	9.2.4 Ash Handling	24
	9.3 Plant Auxiliary Systems	25
10.0	DOMINION BRIDGE-SULZER BOILER DESIGN	25
	10.1 Gas Path	25
	10.2 Boiler, Furnace and Pressure Parts	26
	10.3 Feed Systems for Coal and Limestone	27
	10.4 Wood Chip Firing	28
	10.5 Grit Refiring	28
	10.6 Bed Drain System	28
	10.7 Secondary Heat Recovery and Flue Gas Clean-up	29
	10.8 Bed Light-up	29
11.0	DOMINION BRIDGE-SULZER CONTROLS AND INSTRUMENTATION SYSTEMS	30
	11.1 Control Room	30
	11.2 Control Philosophy	30
	11.3 Fluidized-bed Boiler Controls	30
12.0	SUMMARY OF THE EMR-DND SELECTION PROCEDURE	33
13.0	CONCLUSIONS	34

TABLES

No.		Page
1	Boiler specified capacity and operating conditions	35
2	Particulars of Design Coal (Devco, Prince Mine)	36
3	Particulars of supplementary fuel (Wood Chips)	37
4	Particulars of demonstration fuel (Low grade coal and washery rejects)	37
5	Particulars of design limestone (Havelock Lime Works Ltd., Havelock, New Brunswick)	38

Tables cont'd

No.		Page
6	Comparative data for the two plant designs	39
7	Comparative data on the electrical requirements	40

FIGURES

No.		Page
1	Site layout - Foster Wheeler design	41
2	Site layout - Dominion Bridge-Sulzer design	41
3	Plant layout - Foster Wheeler installation	42
4	Plant layout - Dominion Bridge-Sulzer design	43
5	Flow diagrams for coal, wood and limestone Foster Wheeler installation	44
6	Flow diagrams for coal and limestone Dominion Bridge-Sulzer design	45
7	Sectional elevation - Foster Wheeler boiler	46
8	Sectional elevation - Dominion Bridge-Sulzer boiler	47
9	Schematic of Dominion Bridge-Sulzer combustor supervisory system	48
10	Schematic of Dominion Bridge-Sulzer combustor control system	49

1.0 INTRODUCTION

The project for the installation of two atmospheric-pressure fluidized bed combustion (AFBC) boilers at the Canadian Forces Base Summerside, P.E.I. developed from the requirements of two Canadian Government Departments. These Departments and their particular objectives are:

1. Department of Energy Mines and Resources. (EMR)
   a. To demonstrate AFBC as a viable, clean "off-oil" technology on a commercial scale.
   b. To transfer offshore AFBC technology to Canadian manufacturers and suppliers.

1. Department of National Defence. (DND)

   a. To replace an aging coal-fired steam generating plant at minimum life cycle cost but based upon dependable availability of fuel.
   b. To eliminate a local pollution problem caused by the plant to be replaced, which is adjacent to the administrative and accommodation areas of the base.
   c. To reduce the heating plant staff requirements on the base by reducing the number of heating plants from two to one.

Accordingly the two departments, EMR and DND, co-sponsored the "CFB Summerside Project". By means of a series of contracts two competing teams of designers were engaged to prepare conceptual designs of a heating plant containing two 18000 kg/h FBC steam boilers, and from these develop detailed designs and proposals. The two teams were selected such that one would be utilizing North American technology and the other British technology.

In early 1981, following assessment of the detailed designs and proposals, a contract was placed with one of the groups for the construction of a two-boiler installation to operate in conjunction with an existing boiler plant. The new facility is to be ready for commissioning in the fall of 1982. It has been designed to burn readily available Nova Scotia coal of relatively high sulphur and ash contents, and is also expected to demonstrate a capability for burning somewhat inferior New Brunswick coal. Limestone, which is required as a sulphur sorbent, is readily available in New Brunswick.

This paper descibes the two competitive designs which were tendered, with such updating as necessary on the design selected for construction, to incorporate changes effected since the firm proposals were submitted. Thus the paper reflects the current state-of-the-art of AFBC boilers available in Canada.

2.0 FLUIDIZED BED COMBUSTION

A fluidized bed consists of a mass of granular particles through which an upward flow of air or gas is passed with sufficient velocity to partially lift or "fluidize" the particles. A fuel can be imposed upon or through the fluidized bed, resulting in intimate contact with the bed material and the combustion air passing through it.

A convenient combination results from using limestone as the bed material in conjunction with high-sulphur coal. The combustion heat calcines the calcium carbonate in the limestone into calcium oxide which reacts with the sulphur in the coal to form calcium sulphate, which can be removed from the bed as a non-hazardous solid. This method minimizes the sulphur oxides being carried into the air as pollutants.

For optimum sulphur absorption the bed temperature is controlled between 815°C and 870°C (1500°F and 1600°F). Replacement limestone is fed into the bed to maintain the desired maximum SO_2 emission level at the stack. The bed material inventory is regulated by means of a controlled gravity drain system to maintain the bed at the required depth. Since the normal operating temperature of the bed is below the fusion temperature of the coal ash, the ash does not fuse into clinker or slag and can be removed as a granular product easily handled by a conventional pneumatic solids transport system.

Because the bed residue has a high lime content an environmental study is under way at Summerside to identify a safe disposal site. However, extensive studies by others have concluded that AFBC residues are non-hazardous, and indeed may be useful for agricultural purposes or for stabilizing road-making materials. At Summerside, the method of disposal will be decided upon when actual samples of bed residue and fly ash are available, and their characteristics can be determined.

3.0 BASE HEATING REQUIREMENTS AND FUEL OPTIONS

The Canadian Forces Base Summerside is located in the Province of Prince Edward Island in the Gulf of St. Lawrence. The climate is severe; daily mean temperatures are sub-zero for five months of the year and average wind speeds are approximately 25 km/h. At present, heating for all major buildings is provided by two steam plants connected to distribution steam mains with collecting condensate returns. These two plants, which burn coal on stoker-fired grates, combine to supply a demand for steam which varies from a summer month average of 2200 kg/h to a winter peak of 25000 kg/h. The steam is supplied to the base heating system at a condition of 965 kPa (140 psig) saturated.

Plant No. 1 is old, reaching the end of its useful life as maintenance costs rise. It is situated close to the Base operational and accommodation areas which it was originally intended to service, and creates a local smoke nuisance. It is therefore most desirable that this plant be eliminated.

Plant No. 2, of more recent vintage and in much better condition, was installed in the mid 1950's to heat hangars and other buildings close to the aircraft runways. It is remote from the more populated areas of the base, and is generally downwind, hence any stack emissions will have a less serious effect on personnel. Other benefits would result from extending Plant No. 2 rather than refurbishing Plant No. 1. They include

a. Reduction in personnel requirements due to single plant operation.
b. Less "on-base" transportation requirements for coal since Plant No. 2 is much closer to the coal storage area than Plant No. 1.

With the exception of limited quantities of wood grown on Prince Edward Island all fuel has to be shipped across water. Fuel oil in the Atlantic regon must be imported and hence has the dual disadvantage of high cost and insecure supply. High-volatile bituminous coal is available at reasonable cost from the two neighbouring provinces of New Brunswick and Nova Scotia but quality is poor in several respects, particularly for stoker grate applications. The coal is strongly caking, sulphur ranges from 3 to 8%, ash content is approximately 20% and ash softening temperature is low. These characteristics, when coupled with stringent atmospheric emissions requirements make the stated advantages of fluidized-bed combustion very attractive.

Chipped wood, obtained from land clearing in connection with reforestation projects on Prince Edward Island, is expected to be avaiable, and therefore has been considered as a potential supplementary fuel, although the supply is likely to be limited and the cost has not been clearly established.

In view of the foregoing considerations it was decided to meet the base heating requirements by expanding Plant No. 2, with Nova Scotia coal as the primary fuel, and wood chips as a supplementary fuel. Fluidized-bed combustion was selected as the firing technology, mainly because of its ability to burn high-sulphur coal with minimal SO_2 emissions, but also because Canadian industrial experience with FBC incineration of wood waste has indicated that co-firing of coal and wood waste is feasible.

While plant design was in progress, as described subsequently, steam and condensable piping were laid between Plant No. 2 and the area served by Plant No. 1. When the expanded Plant No. 2 is in service, Plant No. 1 can be decommissioned.

4.0 E.M.R. - D.N.D. REQUIREMENTS

There were a number of major requirements from the two sponsoring government departments which had considerable influence on the design and timing of the CFB Summerside Project.

Those of the Department of National Defence were:

1. That a source of heating steam to replace that from Plant No. 1 be available for the heating season 1982-83.
2. That air pollution be reduced in the operational and accommodation areas of the base.
3. That the new plant be an extension of Plant No. 2 in order to minimize the number of operating personnel required. This also required that the two older boilers in Plant No. 2 and the new boilers be integrated to function as one plant.

Requirements of the Department of Energy, Mines and Resources included:

1. That fludized-bed combustion technology be employed, in order to prove and demonstrate its viability as a clean "off-oil" technology.

2. That it be possible to demonstrate the feasibility of using local Canadian coals, with their specific characteristics, as already described.
3. That the coal delivery and bunkering system be able to cope with wet or frozen coal. This requires that the bunkers be heated, or located within the boilerhouse building.
4. That the coal handling system be so arranged that there would be no interruption of coal supply to the boilers should any one of the conveyors have to be taken out of service for repair or maintenance while the plant is operating.

The purpose of the last two EMR requirements was to ensure, insofar as possible, that the performance evaluation of FBC technology would not be unjustly affected by materials handling problems.

The foregoing considerations were incorporated into a work statement which formed the basis of a series of design contracts subsequently issued by Supply and Services Canada, as described later. The major requirements given in the work statement are as follows:

i) The plant is to be an addition to the existing No. 2 plant at the base. The existing boilers in the plant are to continue in service. The plant addition is to include one new boiler with space for a second boiler. (Subsequently the construction contract provided for both boilers to be installed at the same time).

ii) The design of the new boilers is to be based on fluidized-bed combustion technology with utilization of limestone for sulphur neutralization. The fuels are to be coal and wood chips with analyses as specified. The boilers are to be rated at 18000 kg/h each.

iii) In addition to the two FBC boilers, the plant is to house all necessary auxiliaries such as systems for materials handling, steam, condensate, feed-water and electrical supply, and all necessary cross-connections to integrate the new boilers with the existing boilers and equipment in Plant No. 2.

iv) The buiding height is to be below the aircraft flight zone defined by a 1 in 7 slope from the edge of the runway.

v) Offices, workshop and usual amenities are to be provided.

vi) Normal plant services are to provided, such as accesses for personnel and materials handling, water and sanitary services, lighting, heating, compressed air and fire protection.

vii) A comprehensive system for reception, storage, preparation and handling of coal, limestone, wood chips, fly ash and bed residue is to be included to meet the following specifications:

Coal storage; 96 hours supply for a steaming rate of 25000 kg/h (55000 lb/h)

Limestone storage; 96 hours supply for a steaming rate of 25000 kg/h (55000 lb/h)

Woodchips storage; 12 hours supply for 30% of heat input for steaming rate of 25000 kg/h (55000 lb/h)

Bed drain and fly ash storage: adequate to hold the products from 36 hours of operation of a steaming rate of 25000 kg/h (55000 lb/h). the criterion of 96 hours storage capacity was selected to ensure that transportation of the materials external to the plant could be avoided over long week-ends.

viii) An auxiliary power unit (diesel generator) large enough to supply emergency power to operate one AFBC boiler only in case of power failure, is to be provided.

Further design requirements, including the allowable stack emissions, are given in Table 1. Particulars of the design coal, which is the fuel with which guarantees of boiler capacity, efficiency and emissions are to be met, are given in Table 2. The supplementary fuel, wood chips, is described in Table 3. It is also intended to carry out demonstration tests with fuel of lower quality than the design coal, and the analysis of this "demonstration fuel" is given in Table 4. The design contract requires that the FBC boilers burn the demonstration fuel successfully, but no performance guarantees apply. Table 5 provides analytical data for the limestone selected as the sulphur sorbent.

5.0 DEVELOPMENT OF COMPETITIVE DESIGNS

By early 1977 the conceptual approval for the subject installation had been confirmed and the design requirements had been set. The demonstration project was launched by inviting proposals to prepare a conceptual boiler design. A particular requirement was that the boiler should be available from a Canadian manufacturer.

At the same time, a project management structure was initiated. The project was organized into six phases as follows:

Phase 1:	Conceptual Boiler Design	Completion Dec. 1978
Phase 2:	Conceptual Plant Design	Completion Dec. 1979
Phase 3:	Detailed Design and Tender	Completion Jan. 1981
Phase 4:	Construction of Plant with 1 Boiler	Completion Dec. 1982
Phase 5:	Testing and Demonstration Program	Completion Mar. 1984
Phase 6:	Tendering and Installation of Second Boiler	Completion Dec. 1985.

Seven proposals for boiler design were received, six of them offering American technology, one offering British technology. Careful consideration led to the decision to issue two parallel sets of contracts for Phases 1, 2 & 3, one to the agency offering British technology, the other to one of the agencies offering American technology.

This approach to selection was seen to have the following important benefits:

1. The probability of selecting the best available technology would be improved.
2. Two Canadian manufacturers would be brought to the point of being able to offer fulidized bed boilers.
3. A strong element of commercial competition would be maintained which could affect the tender prices to be submitted at the end of Phase 3.

Accordingly, two contracts were issued for Phase 1: Conceptual Boiler Design. One was awarded to a team comprising the Canadian consulting firm of Intercontinental Engineering Ltd. (INTEG), and Coal Processing Consultants (CPC), the well known U.K. organisation jointly owned by Babcock and

Wilcox Ltd. (UK) and the U.K. National Coal Board. They produced a boiler design based on British technology.

The other contract was awarded to Foster Wheeler Limited, the Canadian subsidiary of Foster Wheeler Energy Corporation of the U.S.A. Their design of boiler was similar to that of an AFBC boiler provided by the Corporation and installed in Georgetown University, Washington, D.C.

The same contractors were subsequently issued contracts for Phase 2: Conceptual Plant Design. Since plant design is outside the normal scope of Foster Wheeler Ltd, they engaged the services of Montreal Engineering Co. Ltd., a Canadian consulting firm prominent in power plant design.

In early 1980 contracts were placed for Phase 3 of the project, which consisted of detailed design and firm price proposals for building a plant under contractor "turnkey" conditions. To identify clearly the responsiblity for boiler performance it was desirable to have the boiler manufacturer assume the role of prime contractor. Since neither Integ nor CPC had manufacturing facilities the problem was solved when a Canadian firm, Dominion Bridge-Sulzer Inc. was licenced by Babcock Contractors Inc. to build boilers to the Babcock-CPC design. Accordingly the Phase 3 contracts were placed with Dominion Bridge-Sulzer Inc. and Foster Wheeler Ltd. for the detailed plant design and firm "turnkey" price proposals. January 5, 1981 was set as the date for completion of Phase 3 and submission of tenders.

DND and EMR monitored the progress of the Phase 3 design contracts closely, in order to minimize the time required to evaluate the two bids and award a contract for construction. This was essential to ensure that the plant would be operational for the heating season of 1982-83.

The two proposals were assessed by a point-rating system which is given later in the paper, and both were found to fully meet the technical requirements. The Foster Wheeler proposal, for which Montreal Engineering Company Limited had prepared the "balance of plant" design, offered a substantially lower price. Some design modifications which could further reduce costs were noted; in addition, it was concluded that the state of the art in fluidized-bed combustion had advanced sufficiently that risk of total failure to perform was minimal. Therefore, it was decided to purchase both boilers at once, thus reducing fabrication and installation costs, and advancing the project completion date by eliminating Phase 6. In subsequent negotiation with Foster Wheeler Ltd., these factors led to a further reduction in the

tender price, and on February 26th, 1981 that firm was awarded a contract in the amount of $13,135,635 for Phase 4, construction of the complete plant with two FBC boilers.

A major purpose of the competitive design contracts was to provide potential users of FBC technology with two Canadian suppliers to choose from. Since the designs put forward by both Dominion Bridge-Sulzer Inc. and Foster Wheeler Ltd. were judged technically acceptable, both will be described in this paper.

6.0 FOSTER WHEELER LTD. PLANT DESIGN

As already mentioned, the Foster Wheeler design was modified in several respects during the negotiations which finally led to award of the contract for contruction, and these modifications are incorporated into the following description.

6.1 PLANT LAYOUT

The site layout is illustrated in Figures 1 and 3. The new plant addition is located across from the firing aisle for the existing boilers, with the new control room placed between the new and the existing boilers. This was necessitated by the need to keep clear of the aircraft flight interference plane associated with the adjacent runway. Also, arranging the boiler fronts of both old and new boilers opposite one another permits a sigle team of personnel to operate all four boilers throughout a shift.

Since the Foster Wheeler boilers are shop-assembled packages, arrangements were made to permit each boiler to be skidded into the building on its back and elevated to its correct position by using the building structure. This is proving to be of considerable assistance in attaining the desired competion date. It has ensured that the building could be virtually completely sheathed in before the onset of winter 1981-82 thereby enabling much of the auxiliary services to be installed under protected conditions while awaiting delivery of the boilers.

The layout of the new boilerhouse is such that the major load-bearing foundations, particularly those supporting the coal bunkers, are kept well clear of the foundations of the original Plant No. 2. The intervening space is conveniently arranged to provide the following:

1. Control room for both old and new units at a height mid-way between their respective firing positions.
2. Superintendent's office at control room level.
3. Washroom at control room level.
4. Motor control centre below grade beneath the control room.
5. Workshop at approximately grade level.
6. Easy access between the two plants.

6.2 MATERIALS STORAGE AND HANDLING SYSTEMS

Figure 5 shows a simplified flow diagram of the storage and handling facilities for coal, wood and limestone. Storage and handling capacities are also listed.

6.2.1 COAL

With the exception of local wood, all fuels have to be shipped to Prince Edward Island. Coal is normally brought in by rail and ferry or by barge to the quayside at Summerside and then trucked to an outdoor stockpile at the base, the stockpile being about half a kilometre from Plant No. 2. Stockpiling is usually carried out in the summer or the fall when transportation and weather are appropriate.

Inevitably, the coal collects water while awaiting use and in winter it is prone to freezing. When the coal is extracted under freezing conditions, efforts are made to remove loose coal from under the frozen crust of the stockpile to facilitate handling at the plant. However, insofar as possible, the plant bunkering system has been designed to cope with wet or frozen coal.

Delivery from the stockpile to the plant is made by dump truck which discharges its load through a "grizzly" with 75 mm square openings into a hopper from which the coal is fed, by means of an elevator, to a vibrating screen. Here oversized coal is separated and passed to a crusher for sizing. The screenings and the crushed coal rejoin and are elevated to a transverse conveyor passing over the tops of four coal bunkers, each having a capacity of 75 metric tonnes. These are arranged so that for normal operation two of them will serve one AFBC boiler while the other two will serve the second AFBC boiler. The bunkers have been located completely within the boilerhouse to minimize the possibility of coal freeze-up while awaiting use. Furthermore,

the discharge cones are lined with stainless steel and fitted with vibrating bin dischargers to reduce the possibility of "rat-holing".

From the bin dischargers, the coal from each pair of bunkers is elevated to a ready-use bin for the associated boiler. Alternatively, by means of a transfer conveyor, shown in Figure 5, either ready-use bin can be replenished from either pair of bunkers. This ensures that if any one item of transfer equipment between the bunkers and the bins fails, both boilers can still be operated.

Coal is extracted from the bins at controlled rates by belt-type weigh feeders, one per boiler, and transferred by a split chute to the two stokers per boiler.

6.2.2 WOOD CHIPS

It had originally been intended that a complete storage and handling system be provided so that wood chips could be used as a supplementary fuel on a continuous basis. Consideration of the overall cost of such an installation, together with uncertainties of price and long term continuous supply of wood chips for this particular plant, led to a modified approach in which the use of wood chips could be demonstrated but not on a continuous basis. This was done by retaining within the design the two ready-use wood chip bins above the boilers but deleting the originally-intended bulk storage and handling facilities.

Instead, it is proposed to use the coal bunkering facilities for receiving the wood chips and elevating them to the transverse conveyor across the top of the coal bunkers. By means of an additional gate on the transverse conveyor the wood chips can be fed to a screw conveyor which fills the wood chip bins. When the coal bunkering system is used for conveying wood chips, the grids will be removed from the vibrating screen in order to bypass the coal crusher.

Wood chips will be fed at a controlled rate by means of weigh-feeders, one per boiler, to a pneumatic spreader on the preferential bed of the associated boiler, as will be described later.

6.2.3 LIMESTONE

The method of handling limestone is very similar to that for coal, except that it is not intended to provide a major stockpile of limestone at

the base. With limestone being brought a relatively short distance from New Brunswick, little difficulty is foreseen in delivering directly to the plant as required. A small stockpile will be provided to guard against possible interuption of deliveries due to ferry difficulties or seasonal load limitations on roads.

It is intended to buy limestone sized as required for the fluidized beds. However, the possibility of having to deal with frozen lumps has been recognized, and therefore after being dumped through a "grizzly" the limestone passes through a screen and crusher arrangement similar to that for coal. It is then transferred by elevator and belt conveyor to two storage bunkers, one per boiler. Each has a capacity of 68 metric tonnes.

From the bunkers the limestone is elevated to ready-use bins, one per boiler, from which it is taken at controlled rates by two weigh feeders per boiler and fed through drop pipes into the respective fluidized beds.

As the provision of limestone is not critical for the production of steam no provision has been made to supply limestone from either bunker to the ready-use bin of the opposite boiler.

6.2.4 ASH HANDLING

A comprehensive system of ash handling is provided for the collection and storage of spent limestone and ash rejected from the fluidized beds, together with fly ash collected in the baghouse filters. A pneumatic eduction system is used wherein a steam exhauster provides the vacuum. A steam exhauster was selected over a motor driven unit to reduce the requirement for electrical power.

An ash silo is provided to give storage for the ash from 68 hours of operation at maximum demand. This deviation from the 96 hour requirement set for coal and limestone storage, to avoid haulage on weekends or during bad weather, was necessary to keep the height of the ash silo below the aircraft flight interference plane. Disposal and potential use of the ash is referred to in Section 2.0 Fluidized Bed Combustion.

6.3 PLANT AUXILIARY SYSTEMS

6.3.1 STEAM AND CONDENSATE SYSTEMS

The steam and condensate systems associated with the new AFBC boilers are virtually self-contained and separate from those of the existing Plant

No. 2. There is, however, cross-connection of the main steam discharge to the base heating as well as to a common service steam manifold which is essentially for plant heating.

Both the old and new plants receive condensate from the base heating systems. The hotwells of the two plants are connected by an appropriate levelling pipe. The hotwell for the new plant has been proportioned to accept the complete drainage of a recently-installed condensate line from the higher accomodation areas of the base as well as from the area in the vicinity of Plant No. 2.

The feedwater system uses condensate pumps to move water from the hotwell to a feedwater heating de-aerator. The de-aerated feedwater is supplied to the boilers by boiler feed pumps, two being steam driven for normal use, with a third being electrically driven. The exhaust steam from the feed pumps is used in the de-aerator. Provision is made to circulate condensate from the hotwell through the boiler bed drain coolers and back to the hotwell to conserve heat. Feedwater make-up is taken from the base raw-water system and passed through a dual water softening unit. Chemical treatment for boiler feedwater and de-aerator water is provided.

6.3.2 LIGHTING-UP FUEL SYSTEM

A simple system supplies No. 2 fuel oil to the lighting-up burner on each boiler and to the emergency diesel generator. It consists of a small storage tank situated outside the boilerhouse at grade level, with gravity flow to the diesel generator and to two transfer pumps, each of full-duty rating, which deliver to the boiler lighting-up burners.

6.4 ELECTRICAL

Considerable electrical power is required to operate the AFBC boilers and since none is normally generated at the boiler plant, it must be provided from external sources either within or outside the base. The contract calls for connections at a substation local to the existing Plant No. 2. A high voltage cable connects the substation to a dry-type transformer in a motor control centre beneath the control room. Distribution is effected from the motor control centre.

A diesel-driven auxiliary power generator is situated at grade level between the two baghouses. It is sized to start up and maintain in operation

either, but not both, of the fluidized-bed boilers. It is always independent of the primary power supply, that is, no paralleling is required. Upon power failure it starts automatically and is suitable for rapid acceptance of load. The major starting loads are those of the forced draft and induced draft fans.

7.0 FOSTER WHEELER BOILER DESIGN

7.1 GAS PATH

The basic layout of the boilers and equipment associated with the gas path is given in Figure 3. The excavation of a basement was necessitated by the requirement to keep the building below the aircraft flight interference plane associated with the nearby runway. The following describes the gas path of one boiler.

The forced draft fan is situated below grade, drawing air from within the boilerhouse through an inlet silencer. The air is ducted to the base of the boiler for distribution through the plenum of the fluidized bed. The flue gases from the combustion zone pass through a water-cooled furnace section, then through a two-pass convection section, into a mechanical dust extractor and thence through an economizer. They are then drawn through a baghouse by an induced-draft fan and discharged to atmosphere through a free-standing stack passing through the roof of the building. The original intent had been to use a single stack for both boilers, external to the plant, to provide greater height for flue gas dispersal. This has been changed to a separate stack for each boiler to reduce cost, to prevent mutual interference in operation, and to facilitate the analysis of flue gases. It should also facilitate boiler control.

7.2 BOILER, FURNACE AND PRESSURE PARTS

A typical cross-section of the unit is illustrated in Figure 7. The boiler furnace and pressure parts are suitable for shop manufacture as a package and are an adaption of a well-proven two-drum water-tube steam generator utilizing natural circulation throughout. The dimensions of the boiler package are such that it can be shipped by rail on a large, flat-bed rail car.

The furnace differs from that of a conventional coal or oil-fired boiler, not only in the provisions for a fluidized bed at the bottom, but also in that it is divided vertically by a membrane wall of tubes extending the full height of the furnace. This divides the bed into two sections arranged

side by side parallel to the boiler drums. The bed closest to the drums is referred to as the preferential bed. It will be in use whenever the boiler is in operation and it is the bed in which combustion is initiated by a lighting-up burner using No. 2 fuel oil. The preferential bed contains no heat exchange surface other than the membrane walls which form it. It requires virtually no refractory. In addition to coal it receives all the wood chips to be burned, the re-cycled fines from the convection bank and fly ash from the mechanical dust collector.

The other bed, which is slightly larger, is called the secondary bed. It will operate at a somewhat lower temperature than the preferential bed and it incorporates immersed heat transfer surface in the form of inclined tubes passing through it. As with the membrane walls these tubes are cooled by natural circulation.

Combustion air is introduced through a large number of stainless-steel bubble caps penetrating the uncooled distributor plates which form the floor of the furnace. The bubble caps project above the distributor plates by a few centimetres and thus leave a layer of undisturbed bed material which serves to insulate the distributor plate. Each bed section is supplied with air from a separately-controlled plenum.

A spreader stoker is provided for each of the two beds. These distribute the coal along the length of the fluidized beds, that is, parallel to the boiler drums. With conventional boiler firing the spreader stoker, with its incorporated chain feeder, meters or controls the rate of coal discharge into the furnace, but with the fluidized-bed boilers the stokers will be set to give the optimum coal distribution across the beds, and metering of the coal to suit steam demand will be carried out upstream by means of weigh feeders. Incorporated in the spreader stoker which supplies the preferential bed there is a water-cooled wood-feeding spout which injects wood chips by a combination of air jets and gravity. Wood is fed to the preferential bed only.

The limestone is admitted to each bed by a drop pipe at the end of the bed remote from the coal feeder. The drop pipe terminates at approximately the upper level of an expanded bed. The bed drains, on the other hand, are located at the coal feeder ends of the beds. Hence the limestone must traverse the entire length of the bed before reaching the discharge, thereby

maximizing the residence time available for reaction. The limestone feed rate is controlled by weigh feeders upstream of the drop pipes.

The furnace cavity is tall, (approximately 8 m) and the flue gases leave at the highest point to enter the convective heat transfer zone of the boiler. The tall furnace is expected to facilitate completion of combustion and neutralization reactions as well as heat transfer.

7.3 FEED SYSTEMS FOR COAL, WOOD AND LIMESTONE

The feed systems located directly on the boilers have already been described. Immediately upstream, for each boiler, coal is fed from its ready-use bin via a vibrating bin discharger to a weigh feeder which controls the coal feed rate. It discharges to a dividing chute which, with appropriate gating, permits the coal to flow either to both of the spreader stokers on the boiler or to the one for the preferential bed only.

The ready-use bins for the wood chips are live bottom designs which discharge to one weigh feeder per boiler. Each weigh feeder in turn discharges through a chute to the injection spout incorporated in the spreader stoker on the preferential bed.

Each boiler has two weigh feeders controlling the supply of limestone, one for each of the fluidized beds. From the weigh feeders the limestone is fed directly to the respective beds through the drop pipes.

All weigh feeders are integrated into the overall boiler control system.

7.4 CARBON RECYCLE

Due to the highly turbulent state of the fluidized bed, there will inevitably be a carryover of unburned carbon and limestone fines out of the furnace. Some of these will be deposited in the hopper beneath the two-pass convection section of the boiler. A much larger quantity will be trapped by the mechanical dust collector located between the boiler and the economizer. This carried over material is re-injected into the preferential bed a short distance above the air distributor plate. The two streams are handled separately. Those from the hoppers beneath the boiler bank are re-injected by pneumatically-operated eductors on a continuous basis. Those from the mechanical collector are re-injected batch-wise through Permaloc double gate valves and hoppers. The latter system requires less power for operation than the

continuously-operated eductors, but space and height limitations precluded its use under the boiler bank.

In addition to improving carbon burn-out, and therefore boiler efficiency, the recycle system is expected to improve limestone utilization.

7.5 BED DRAIN SYSTEM

The bed drain system serves the dual purposes of varying the bed level in each cell to suit changing load conditions and of removing largely-spent limestone together with residual ash from the coal. As mentioned above the bed drain pipes are at the ends of the beds remote from the limestone supply pipes to give maximum residence time for the limestone. The bed drain pipes, one per bed, pass from the bed at the level of the air distributor plate down through the air inlet plenum to bed drain coolers located under the boilers.

The bed drain coolers, one per bed, are water-cooled twin-screw conveyors driven by direct-current controllable-speed motors. The boiler control system varies the rotational speed of the screws, and thus controls the rate of extraction and the bed level. In the interest of thermal economy the bed drain coolers are circulated with condensate which is taken from and returned to the main hotwell. Thus the heat given up in the bed drain coolers is returned to the boiler feedwater.

The bed residue expelled from the drain coolers passes into hoppers from which it is automatically transferred by the ash handling system to the ash storage silo for disposal.

7.6 SECONDARY HEAT RECOVERY AND FLUE GAS CLEAN-UP

To meet the design requirements for a maximum stack temperature of 175°C an economizer is located downstream from the mechanical dust collector. It is of finned tube design and is fitted with a single soot blower.

Final gas clean-up with respect to particulates is accomplished by means of bag filters. Each boiler has a baghouse located downstream of the mechanical dust collector and economizer. Thus the baghouse needs only to contend with relatively cool gas, laden with fine particulates. Teflon-coated bags are arranged in 12 cells of 36 filter tubes each. Cleaning is achieved by shock pulsing a reverse air flow sequentially to each cell. This dislodged fly ash accumulates in the conical hoppers beneath the filter tubes, and is

removed by the pneumatic ash handling system which also serves the bed drain coolers.

7.7 BED LIGHT-UP SYSTEM

Each boiler is lighted-up by heating the preferential bed with an air-atomized light-oil-fired ignition burner provided with a propane gas pilot. The fuel oil supply system has already been described. The ignition burner is managed from a local panel which provides control and interlocking for flame proving, safety shut-down and air regulation. It is also integrated with the boiler operating panel in the control room. The ignition burner is positioned at the coal feeder end of the preferential bed just above the slumped level of the bed, and is angled downward so that the flame impinges upon the upper surface of the bed.

The normal start-up procedure with a cold bed is as follows:-

1. Charge each bed cell with calcined limestone to a depth of 0.5 m.
2. After purging the ignition burner, fluidize each bed for 5 minutes each, then together for 5 minutes, then slump both beds.
3. Light the ignition burner and fire it over the slumped preferential bed for 30 minutes.
4. With the ignitor still operating "fluff" the preferential bed by fluidizing for 5 seconds. Repeat the 5 second "fluffing" every 15 minutes until the bed temperature levels off between 150°C and 200°C.
5. Fluidize the bed for 10 minutes and feed approximately 50 kg of coal while monitoring O_2 and bed temperature. If the temperature rise and O_2 falls, a coal fire is indicated and coal feed is increased. If after 10 minutes a coal fire is not indicated, slump the bed and repeat Step 4. The ignitor is left in operation until the bed temperature reaches 800°C.
6. Once the preferential bed is at full temperature the secondary bed is ignited by opening a slide gate in the partition wall. Rapid mixing of the two beds occurs, resulting in the ignition of the secondary bed.

8.0 FOSTER WHEELER CONTROLS AND INSTRUMENTATION SYSTEM

8.1 CONTROL ROOM

As mentioned earlier part of the space between the main structures of Plant No. 2 and the new boilerhouse is used for a control room, from which all four boilers, that is, the two existing units and the two new AFBC units, will be controlled and supervised.

The control room is at an elevation approximately half-way between the firing levels of the old and new boilers, with ready access both ways. It will be air-conditioned to ensure both operator comfort and a suitable environment for the electronic equipment and instrumentation.

Major functions to be carried out from the control room include:-

1. Overall supervision and control of the AFBC boilers.
2. Overall supervision and control of the two older boilers.
3. Supervision and control of coal, wood, limestone and ash handling systems.
4. Supervision of all auxiliary systems, that is, steam, condensate and feedwater systems.
5. All recording and data-logging functions.

8.2 CONTROL PHILOSPHY

A centralized control philosphy has been adopted whereby the fluidized-bed boilers can be started up, operated and shut down from the control room. Certain operations which are only carried out on start-up or shut-down of the boilers or which normally function automatically, are controlled from local stations outside the control room. The existing stoker-fired boilers are supervised from the control room but are started up and shut down from control centres local to the boilers.

8.3 FLUIDIZED-BED BOILER CONTROLS

The control panel consists of four sections; one for each AFBC boiler, one for the two existing boilers, and one for common services. Each section provides centralized control, indication, recording and alarm annunciation.

Control of the boiler feedwater, air flow, coal and limestone feed, and bed level are provided by a Bailey Controls 820 Series electric analogue

control system. All boiler control loops are regulated by means of Bailey operator control stations located on the panel.

The following loops are provided for each boiler:-

1. Plant Master - to develop a demand for fuel and air flow for each boiler based on an indication of plant load. Header pressure is used as the demand signal.
2. Fuel Flow - to maintain fuel flow to the beds to suit load demand and air flow and to keep bed temperatures within allowable limits. Boiler master demand, air flow, fuel flow, bed temperature and oxygen in the flue gas are used to develop the control signal for each bed.
3. Air Flow - to maintain air flow in balance with load demand and fuel flow. The control signal for each bed is developed from boiler master demand, fuel flow, and oxygen in the flue gas.
4. Limestone Feed and Bed Drain - for each bed, to supply sufficient limestone and to control bed drain rate to maintain the bed level within prescribed limits. The limestone feed signal is developed from fuel flow, SO_2 in the flue gas, and limestone flow. The bed drain speed is regulated by a signal developed from bed level and limestone feed.
5. Feedwater Flow - to maintain feedwater flow at the same rate as steam flow and to keep the level of water in the steam drum at the desired value. A two-element controller measuring steam flow and drum water level is used.
6. Miscellaneous Air Flows - to maintain the forced draft fan discharge pressure and primary air flow at the required level by control of the fan inlet vanes.
7. Furnace Pressure - to maintain the furnace pressure within a narrow band about a set-point value to ensure satisfactory combustion of fuel and safe unit operation. Total boiler air flow demand and furnace pressure are used to develop the signal which controls the inlet vanes of the induced draft fan.
8. Boiler Purge - to ensure that the ignition burner and the entire boiler are purged of all combustibles before a boiler start-up sequence is initiated.

Normally the foregoing loops are expected to function automatically, but the control stations also provide manual operation modes.

8.4 CONTROLS FOR MISCELLANEOUS EQUIPMENT AND SYSTEMS

Other controls include:-

1. Ash Re-injection System - The ash re-injection system with its associated blowers will be controlled from a panel mounted locally. It will normally function automatically and unattended.
2. Wood Chip Feed Conveyor - Each boiler is provided with a screw conveyor to deliver wood chips from the wood chip storage bin to the preferential bed. The speed of the conveyor is regulated manually from an operator station in the control room.
3. Ignition System - The ignition burner is controlled from a local panel which is also integrated into the control room panel so that the burner can be started up, shut down and tripped on a master fuel trip. A purge sequence can also be initiated from the control room.
4. Baghouse - The baghouse is provided with an air blower for sequential cleaning of the bag modules. A local panel automatically controls the cleaning sequence according to an adjustable time cycle.

In general all plant common services are operated and are monitored from the control room. Exceptions are the diesel generator; air compressors; water treatment system; chemical feed sys ; and heating and ventilating system, all of which are operated locally. A common services control panel in the control room provides centralized indication, recording, alarm annunciation and operation. These functions are achieved by conventional technology and therefore will not be described here.

Instrumentation is in excess of what would normally be supplied for a conventional boiler installation, in order to facilitate the testing and demonstration trials planned for the AFBC boilers.

8.5 MATERIALS HANDLING SYSTEMS

In general the materials handling systems are designed to be operated from the control room. Exceptions to this are the filling of the wood bins, manual operation of isolating gates on the coal and limestone bunkers and bins, ash silo operation and coal and limestone receiving operations. All these functions are performed locally. No attempt has been made to integrate the fuel handling of Plant No. 2 with that of the AFBC boilers.

Control panels are provided in the control room for the following systems:-

1. Coal handling.
2. Limestone handling.
3. Ash handling.

The coal and limestone handling systems both consist of two sub-systems. The first transports the material in question from the receiving hopper to the storage bunkers; the second transfers the material to the appropriate ready-use bin. Each system is operated from the corresponding panel in the control room, and mimic diagrams provide a convenient display of what is happening. The systems are conventional, but highly automated with interlocks and local trips.

The ash handling system can be operated entirely from the control room. The operator can manually select and unload any one of eight unloading stations, or he can program the controls to sequence automatically through the stations, in any order.

9.0 DOMINION BRIDGE - SULZER PLANT DESIGN

9.1 PLANT LAYOUT

As with the Foster Wheeler design the boilerhouse for the Dominion Bridge - Sulzer Inc. (DB-S) design is located on the side of Plant No. 2 remote from the adjacent aircraft runway.

The major aspects in which the DB-S design differ from the Foster Wheeler design are as follows:-

1. The coal, limestone and wood chip receiving hoppers are in a structure separate from the boilerhouse building as shown in Figures 2 and 4. This structure also accomodates the coal breaker and limestone crusher.
2. Approximately 75% of the specified storage capacity for coal and limestone would be held in outdoor silos which would be heated and insulated to avoid handling problems due to freezing.
3. The external storage would result in a smaller boilerhouse structure.
4. The control room would be at grade level between the new and old boilers instead of elevated as with the Foster Wheeler design.
5. The new boilers would make use of the existing hotwell in Plant No. 2 instead of providing additional condensate storage capacity.

9.2 MATERIALS STORAGE AND HANDLING SYSTEMS

Figure 6 shows simplified flow diagrams and capacities of the storage and handling facilities for coal and limestone. The receiving hoppers for these and the wood chips are a common, free-standing structure.

9.2.1 COAL

Coal is delivered by dump truck into a receiving hopper with its top at grade level. It is then discharged by a vibrating feeder to a frozen-coal crusher beneath the hopper, and raised by a Redler conveyor to the top of the coal storage silo. Because the silo is located out-of-doors, it is insulated and its conical base is heated. Assisted by a vibrating bin discharger at the base of the silo, the coal is then raised by either of two Redler conveyors to associated horizontal distributing conveyors, which deliver to any of six bunkers, three per boiler. The elevating and distributing conveyors are duplicated to ensure that the full coal storage capacity is available to the boilers even if one conveyor breaks down. The coal then feeds by gravity to water-cooled screw conveyors, one per bunker, which deliver to the fluidized beds.

9.2.2 LIMESTONE

The limestone is handled in a very similar manner to the coal except that only a single set of conveyors is used to transfer the limestone from the silo to the bunkers. A limestone crusher takes the place of a frozen-coal crusher. Each limestone bunker is paired with a coal bunker, and discharges into a rotary feeder which doses the limestone into the same water-cooled feeder that delivers coal to the fluidized bed.

9.2.3 WOOD CHIPS

The proposed system for handling wood chips is somewhat more complex. From the receiving hopper, the wood chips pass via a vibrating bin discharger to a vibrating screen. Oversize material, including twigs, are fed through a hammer hog, then re-combined with the screenings and transferred by means of a Redler conveyor to an outdoor storage silo. This, like the coal silo, is insulated, has a heated hopper and a vibrating discharger. From the silo the wood chips are transported by a Redler conveyor, a transfer conveyor and a bunker distribution conveyor, to two wood chip day bunkers, one per boiler. A re-cycle conveyor system is also provided to move wood chips from the distribution conveyor back to the storage silo. This was included in the proposal to permit wood chips to be moved even when they are not being burned, and thus reduce the risk of them settling and jamming in the silo. Finally, screw feeders, two per bunker, deliver the wood chips from the bunkers to air-swept spouts discharging above the fluidized beds.

9.2.4 ASH HANDLING

The DB-S design proposes a pneumatic transport system to handle the bed residue and fly ash, similar to the system proposed by Foster Wheeler, but differing in several details. Small collection vessels, called blow tanks, eight per boiler, are located as follows:-

1.	- at the discharge of each bed drain cooler.	total of 3
2.	- at the discharge of the mechanical collection hopper.	total of 1
3.	- at the discharge of the economizer hopper.	total of 1
4.	- at the discharge of each baghouse hopper.	total of 3

Each blow tank is equipped with double-lock gate valves. Additional components are an ash recycle bin and a large outdoor ash storage silo. The pneumatic transport system, powered by a motor-driven exhauster, sequentially conveys the ash from each blow tank to either the recycle bin or the storage silo, as desired. A separate system, described later, conveys the ash from the recycle bin back to the fluidized beds for improved carbon burn-up and limestone utilization.

With the ash handling system just described, it is possible to re-cycle fly ash from the bag filters, as well as from the mechanical collector and the economizer.

9.3 PLANT AUXILIARY SYSTEMS

The steam and condensate systems proposed by DB-S are conventional and comparable to those put forward by Foster Wheeler.

The only major differences are:-

1. DB-S does not propose to provide increased hotwell capacity to suit the increased flow and possible surge of condensate from the area now served by Plant No. 1.
2. To remove heat from the bed drain coolers, a closed-circuit water system is proposed, the heat sink being an air-cooled heat exchanger in the forced-draft blower discharge to the furnaces.

The lighting-up fuel system is comparable with that of Foster Wheeler, except that a 22 500 litre tank, insulated and heated, is proposed.

The electrical system proposed by DB-S, like the Foster Wheeler proposal, includes an emergency diesel generator with sufficient capacity to operate one AFBC boiler. The only major difference is that the DB-S proposal includes a small uninteruptable power supply to accomodate the needs of the microprocessor boiler control system which is described later.

10.0 DOMINION BRIDGE - SULZER BOILER DESIGN

10.1 GAS PATH

The basic layout of the boilers and equipment associated with the gas path is given in Figure 4. The following describes the gas path of one boiler.

A single forced-draft fan, situated below grade level, draws from within the boilerhouse through an inlet silencer and discharges into the wind-box below the furnace. Situated in the forced-draft fan discharge duct is a combustion air heater which is a water-to-air exchanger recovering heat from the bed ash coolers. The air then enters the fluidized bed, where combustion takes place. The consequent flue gases pass through a water-cooled freeboard zone, an integral convection section, a mechanical dust collector, an economizer and a three-section baghouse. An induced-draft fan then discharges the gases through a stack. Each boiler has its own stack.

10.2 BOILER, FURNACE AND PRESSURE PARTS

The boiler, which Figure 8 shows in cross-section, has been designed as a field-erected unit. The pressure parts are designed around a conventional two-drum water-tube steam generator utilizing natural circulation, but with a special combustion chamber to suit the specific type of fluidized-bed operation. However, heat exchange surfaces immersed in the bed are cooled by forced circulation. The combustion chamber has a freeboard zone made up of membrane-wall roof and side walls extending down to the level of the mud drum. Gas passage through the convention bank is direct single pass with no baffles.

The fluidized bed is contained in a refractory-lined combustion chamber located below the water-cooled freeboard zone. The base of the combustion chamber is formed by the windbox and air distributor plates, which are penetrated by ash re-injection nozzles and bed drain pipes. Connections are provided through the refractory walls for start-up oil burners, coal and limestone feeders, and wood chip spouts. The height of the refractory combustion chamber below the water-cooled portion of the furnace was selected to provide a fluidized bed depth of 0.9 metres with a freeboard above that of 1.9 metres, which is termed the "splash zone". This is intended to minimize the carry-over of fine particles and to improve the combustion efficiency by providing adequate residence time for the elutriated carbon particles to burn.

The windbox consists of three troughs, equal in size, oriented at right angles to the centrelines of the boiler drums. Air passes from the troughs through "nozzle stand-pipe" distributors welded or screwed into the distributor plates. The stand-pipes consist of small pipe stubs closed at the top and having a series of radial holes drilled around a circle close to

the top. With optimization of spacing and hole sizing this type of distributor has been proven to provide good fluidization of the bed.

Optimum sulphur capture requires that the bed temperature be maintained at 850°C ± 50°C. This necessitates a significant amount of heat extraction from the bed, which is accomplished in the DB-S design by a two-pass bank of cooling coils which pass through the bed at right angles to the wind-box troughs, parallel to the boiler drum axes. The tubes are cooled by forced circulation with boiler water taken from and returned to the steam drum.

A series of ash hoppers are provided on either side of the mud drum to collect particles deposited from the flue gases passing through the convection bank. Since these particles contain high proportions of carbon, together with incompletely-reacted limestone, an eductor system is provided to re-inject them into the splash zone of the furnace, through ports in the rear wall of the combustion chamber.

10.3 FEED SYSTEMS FOR COAL AND LIMESTONE

Over-bed coal feed was a design requirement laid down by EMR and DND, and the DB-S method for achieving it differs radically from that used by Foster Wheeler.

With the coal and limestone bunkers paired, three of each per boiler, as shown in Figure 4, it is possible to transfer coal directly from each coal bunker into the furnace by means of horizontal screw conveyors, as follows:- Coal is fed from each bunker by means of a variable-speed screw conveyor at a rate determined by the boiler control system. The coal is transferred to a fixed-speed, water-cooled screw conveyor which passes through the refractory combustion wall, a short distance above the expanded bed height, and terminates about one third of the distance across the furnace, as shown in Figure 8. Although the fluidized bed has no division walls, it is in effect divided into three zones by the windbox troughs, thus each bunker with its two screw conveyors provides the fuel supply to one trough or zone.

Each limestone bunker is equipped with a variable-speed rotary valve, regulated by the boiler control system, which meters limestone into the corresponding variable-speed coal conveyor. The screw pitch of the coal conveyor is increased at this point to accomodate the additional volume, and the coal/limestone mixture passes into the furnace via the water-cooled screw conveyor

already described. The latter operates at high speed to minimize residence time in the conveyor trough.

10.4 WOOD CHIP FIRING

Each boiler is provided with a two-compartment day bunker for wood chips. A variable-speed screw feeder at the bottom of each compartment delivers the wood chips to air-swept spouts which penetrate the furnace wall a little above the coal/limestone screw feeders. As opposed to the coal/limestone feeders, only two wood chip feeders are provided per boiler. Propelling air is taken from the discharge of the forced-draft fan.

The criteria for the design were:-

1. To ensure that the wood chips are injected into the furnace with minimum elutriation.
2. To provide an adjustable rate of flow.
3. To provide an adjustable spread of fuel.

10.5 GRIT REFIRING

The DB-S grit refiring system corresponds to the Foster Wheeler carbon recycling system. One major difference is that the DB-S system provides for the recycling of baghouse fly ash if desired. Grit from the boiler convection banks is re-injected directly into the furnace by a separate eductor as already described. Fly ash from the mechanical dust collector, the economizer and the baghouse may be transferred to the recycle bin or the ash disposal silo as desired. From the recycle bin the fly ash is re-injected by a method developed in the U.K. which takes an under-bed route but discharges above the level of the bed cooling tubes. It is the opinion of the DB-S designers that the recycle of the baghouse ash may be necessary to achieve adequate carbon burn-up with some coals.

10.6 BED DRAIN SYSTEM

A bed drain system is included in the DB-S design which is similar to that of the Foster Wheeler design except that there are three water-cooled bed drain coolers per boiler instead of two. Also, single-screw units are proposed as against the twin-screw units in the Foster Wheeler design. There

is one bed drain per bed zone or windbox trough. Again, the units are variable-speed, controlled by the centralized control system. The cooled bed residue is transported by the pneumatic ash handling system to the outdoor ash silo for disposal.

10.7 SECONDARY HEAT RECOVERY AND FLUE GAS CLEAN-UP

An economizer is located downstream from the mechanical dust collector. It is a cross-counterflow unit with finned steel tubes arranged in line.

Final particulate removal is accomplished by a three-compartment bag filter of the "walk-in plenum" configuration with one compartment "off stream" for cleaning. Each compartment or module contains 144 Teflon bags suitble for continuous duty at 260°C. The flue gases would bypass the filter units if the above temperature is exceeded under upset conditions.

As already described, the fly ash from the three sections of the baghouse can be conveyed pneumatically either to the recycle bin for re-firing or to the ash silo for disposal.

10.8 BED LIGHT-UP

The bed lighting-up system consists of two oil-fired burners, arranged for simultaneous opposed firing through the boiler walls. The burners produce as intense "hard" flame as this has proved to be more effective than a long lazy flame. Because of the intensity of the flame, it is important to ensure that the bed height is sufficient under all conditions to cover the immersed bed tubes.

The method for lighting up the DB-S furnace is as follows:

1. The boiler must be filled with water and forced circulation to the immersed bed tubes must be established.
2. The bed is fluidized.
3. The ignition burners are brought into operation, keeping the bed fluidized.
4. When the bed temperature reaches 650°C, coal feed is started.
5. When the bed temperature reaches 750°C the ignition burners are shut down.

The ignition burners are sized to provide a warm-up rate of about 3.5°C/min., which minimizes expansion stresses on the pressure parts of the boiler.

11.0 DOMINION BRIDGE - SULZER CONTROLS AND INSTRUMENTATION SYSTEMS

11.1 CONTROL ROOM

As the firing levels of both the existing Plant No. 2 boilers and the AFBC boilers would be at grade level in the DB-S design, the control room was also to be at grade level between them. To meet the common EMR-DND requirements, the control room functions and philosophy of the competing designs were comparable.

11.2 CONTROL PHILOSOPHY

The control system provides for almost complete operation of the fluidized-bed boilers, including start-up and shut-down, from the control room. A high degree of automation is provided by means of a Bristol UCS 3000 mini-computer control system, which carries out data recording functions as well.

The fluidized bed in controlled by changing both its temperature and area. For example, as steam demand reduces, fuel and air are reduced and bed temperature begins to fall. When it reaches a predetermined lower limit, the bed area is reduced by taking one windbox trough, or a portion of one, out of service. Each trough is equipped with dampers which permit all of it, or only a portion of it, to be fluidized. Since there are three troughs, this means that the bed area can be reduced by increments, from the full area to something less than the area of one trough. This makes possible a high degree of turn-down and rapid load following.

11.3 FLUIDIZED-BED BOILER CONTROLS

The boiler control system is shown schematically in Figures 9 and 10. The major components or loops of the system are as follows:-

1. Boiler Load Control - To meet the load demand on the boiler while keeping the bed temperature within the allowable range, this system automatically carries out fluidizing and slumping sequences for each trough.

2. Combustor Supervisory Control - This system accepts the steam flow demand signal from the boiler master, modifies it according to whether wood chips are fired or not, and, taking account of the operational status of the windbox troughs and grit refiring system, develops a set point for the bed temperature controller. If necessary, it commands the fluidization or slumping of a trough section.
3. Bed Temperature Control - This adjusts the firing rate of the trough to bring the bed temperature to the set point.
4. Trough Combustion Control - Each trough is equipped with a system to maintain in it, the correct air/fuel ratio, coal/limestone ratio and fluidizing velocity, based on measurements taken from that trough system only. Thus abnormal conditions in one trough have little effect on an adjacent trough.
5. Trough Sequence Controls - Each trough is provided with automatic sequence controls to ensure that fluidizing, firing and slumping are carried out correctly.
6. Trough Supervisory Control - Each trough has a logic system which signals the required running condition to the feed system. The operator can select which troughs are to be fired or slumped; alternatively, the selection can be made automatically.
7. Bed Temperature Monitor - Each trough has multiple bed temperature sensors which are displayed to the operator and trigger action by the trough supervisory control.
8. Fuel/air Ratio - The load demand signal will be split into individual fuel and air demands for each trough, adjusted if wood chips are being fired, and compared with measurements of combustion air flow and feeder speed to ensure that there is always adequate excess air. Fuel/air ratio is normally constant but can be adjusted by the operator.
9. Fuel Feed Control - Fuel demand is split into a coal feeder rate signal and a proportional limestone feeder rate signal, which respectively control the variable speed drives on the coal and limestone feeders. The coal/limestone ratio can be manually adjusted; an SO_2 analyzer is provided.

10. Wood Chip Feed Control - The rate of wood chip feed is determined by the supervisory control stage, which controls a variable-speed belt conveyor charging the wood chip day bunker.
11. Grits Re-firing Control - Grits from the recycle bin are re-injected into the base of each trough through a single nozzle. A variable-speed rotary lock, operating in line with the coal firing rate, controls the injection rate. Grit recycle starts automatically once stable bed conditions have been established in a trough.
12. Combustion Air Flow Control - This system, one per trough, operates the combustion air dampers to maintain the correct fuel/air ratio. During start-up, when there is no fuel feed, it provides a pre-set fluidizing velocity in the bed.
13. Bed Level Control - In each trough, bed level is computed from windbox pressure with compensation for air flow. On detection of high bed level, a de-ashing cycle is initiated.
14. Ash Removal - Ash removal from the ash hoppers to the storage silo is supervised by a separate control system with a separate panel, but it is activated by signals from the microprocessor controller.
15. Combustion Air Fan Pressure - Fan pressure is controlled by adjusting intake dampers. The set point is automatically adjusted to minimize power loss.
16. Furnace Pressure - This is maintained close to neutral by adjustment of the induced-draft inlet dampers.
17. Steam Pressure - The boiler master pressure controller will act on the combustor supervisory control system to maintain a constant boiler exit pressure.
18. Drum Level - This will be maintained by a three-element level control system.
19. Ignition Oil Burners - Each burner has a modular management system which supervises the light-up, operating and shut-down sequences. The operator has full control of the start and stop actions from the instrument panel, and the computer controls the firing rate to obtain a slow temperature rise in the boiler.

12.0 SUMMARY OF THE EMR-DND SELECTION PROCEDURE

There was no reason to doubt that both competing organizations could put forward designs which would comply with the stated EMR/DND requirements. Details between the two designs were expected to vary considerably. Accordingly, a "points" system of evaluation was evolved so that the Contractor would be selected on the basis of the assessed best value to the Crown, taking into account scientific, financial and socio-economic factors.

The Selection Committee which reviewed the design and tenders was made up of representatives from the Department of National Defence (DND), Department of Energy, Mines and Resources (EMR) and Defence Construction (1951) Ltd. (DCL). In addition representatives from the Department of Supply and Services (DSS) and Environment Canada (EC) were observers to the selection procedures.

The proposals were considered from two aspects, namely:-

1. Plant design for 100 points.
2. Boiler design for 120 points.

These were subdivided as follows:

	1. Plant Design	Max. points
a.	Building layout and facade	10
b.	In-plant storage, preparation and handling facilities for coal, wood chips, fuel oil, limestone etc.	20
c.	Plant services, water, electricity, etc.	10
d.	Control room and office space	5
e.	Workshop and storage for spares and supplies	5
f.	Receiving and storage for coal, wood chips, fuel oil and limestone	15
g.	Preparation and transfer system for coal, wood chips, fuel oil and limestone	20
h.	Manpower requirements	15
	Maximum score for plant design	100

2.	Boiler Design	Max. points
a.	Drawings and specifications	10
b.	Fuel flexibility	10
c.	Boiler efficiency	15
d.	Load following capability	10
e.	Air and flue gas systems	15
f.	Fuel systems and combustor	20
g.	Meters, instruments and controls	15
h.	Contingency plan	5
i.	Manufacturer's previous experience and technology	15
j.	Miscellaneous	5
	Maximum score for boiler design	120

Tables 6 and 7 compare several aspects of the two designs. Both proposals were considered suitable for viable installations. However, largely on the basis of price the Contract was awarded to Foster Wheeler Limited, as previously explained.

13.0 CONCLUSIONS

The approach taken by the sponsoring government departments, letting competitive contracts for first conceptual boiler designs, then conceptual plant design to accomodate the boilers, and finally definitive boiler plant designs with firm price tenders has assisted in making fludized-bed boilers available from Canadian manufacturers.

The award of a contract for a plant to be in service for the heating season 1982-83 has maintained the momentum.

It is expected that on the scheduled date Canada's first two AFBC boilers will be ready to demonstrate that a new technology is available to burn high-sulphur, high-ash coals on a commerical scale with minimal emission of atmospheric pollutants.

Table 1 - Boiler specified capacity and operating conditions

Full load continuous capacity		18000 kg/h (40,000 lb/h) steam
Continuous efficient capability		4000 kg/h (9,000 lb/h) steam
Steam condition		99.9 % dry saturated
Steam pressure		760 to 965 kPa (110 to 140 psig)
Feed water temperature		165°C (221°F)
Boiler efficiency		80% min based on design coal at 5% moisture
Stack temperature		175°C (350°F) max.
Availability		Minimum of three months of continuous 24 hours-a-day operation.
Scheduled down time		Maximum 60 days per year.
Load following capability		Adequate to meet normal variations in plant demand as identified from plant records
Emissions	SO_2	2.96 kg/10^6 k.cal. heat input (1.64 lb/10^6 BTU heat input)
	Particulates	0.36 kg/10^6 k.cal. heat input (0.2 lb/10^6 BTU heat input)
	Visible emissions	Opacity of gases emitted to ambient not to exceed 5% as determined by the Environmental Protection Service of Environment Canada.

Table 2 - Particulars of Design Coal (Devco, Prince Mine)

Proximate Analysis		Dry Basis	Range
Mositure	%	0.0	0 - 10
Ash	%	19.3	16 - 22
Volatile Matter	%	33.5	
Fixed Carbon (by Diff.)	%	47.2	
		100.0	

Ultimate Analysis		Dry Basis	Range
Carbon	%	64.2	
Hydrogen	%	4.0	
Sulphur	%	5.5	5 - 6
Nitrogen	%	1.0	
Ash	%	19.3	16 - 22
Oxygen (by diff.)		6.0	
		100.0	

Calorific Value		
MJ/kg, gross	26.7	23.2 - 27.7
BTU/lb, gross	11,500	9,970 - 11,900

Ash Fusion Temperature	Reducing	Range
Initial	1175°C (2150°F)	1100 - 1200°C
Softening, spherical	1305°C (2380°F)	
Softening, hemispherical	1355°C (2470°F)	1140 - 1375°C
Fluid	1375°C (2510°F)	1200 - 1400°C

Ash analysis (Typical)

SiO_2	39.7%	Al_2O_3	25.5%	Fe_2O_3	27.0%
TiO_2	1.2%	P_2O_5	0.7%	CaO	1.0%
MgO	0.5%	SO_3	0.7%	Na_2O	2.7%
K_2O	2.3%				

Size Consist:- 50 mm (2 in.) x 0 with a maximum of 20% less than 0.6 mm (28 mesh)

Table 3 - Particulars of supplementary fuel (Wood Chips)

Ultimate Analysis		Dry Basis	Range	
Carbon	%	49.5		
Hydrogen	%	6.0		
Oxygen	%	42.0		
Nitrogen	%	1.0		
Ash	%	1.5	0.5 - 3.0	
Moisture	%	0.0	30 - 60	
Calorific Value				
MJ/kg, gross		20.2	8.1 - 14.2	(as fired)
BTU/lb, gross		8700	3480 - 6090	

The wood chips would be a mixture of hardwood and softwood from a tree chipper, giving a size consist of:- 25 mm (1 in.) x 0 but including twigs up to 50 cm (20 in.) long.

Table 4 - Particulars of demonstration fuel
(Low grade coal and washery rejects)

Proximate Analysis			
Ash	40% max.	Calorific Value	
Moisture	12% max.	MJ/kg, gross	20.2
Sulphur	9% max.	BTU/lb, gross	8700

Ash Fusion Temperature, Initial 1000°C (1832°F) min.

Size Consist:- 50 mm (2 in.) x 0 with a maximum of 40% less than 0.6 mm (28 mesh)

Table 5 - Particulars of design limestone
(Havelock Lime Works Ltd., Havelock, New Brunswick)

	As Element, %	As Oxide, %
Loss on ignition at 1800°F	42.60	42.60
Si (SiO_2)	0.63	1.35
Al (Al_2O_3)	0.08	0.15
Fe (Fe_2O_3)	0.12	0.17
Ca (CaO)	39.52	55.33
Mg (MgO)	0.41	0.08
S	0.01	
Total	83.37	100.28

Est. Ca present as $CaO + Ca(OH)_2$	:	0.05%
Est. Mg present as $MgO + Mg(OH)_2$	:	0.01%
Est. Ca present as $CaSO_4$, assuming all S present as $CaSO_4$	:	0.17%

The above indicates the Design Limestone as being approximately 98% $CaCO_3$.

Table 6 - Comparative data for the two plant designs

These data are predicted performance per boiler operating at 100% M.C.R.

		Foster Wheeler Design	D.B.-S. Design
Steam Flow	kg/h	18150	18150
Outlet Pressure	kPa	965	965
Outlet Temperature	°C	182	Dry saturated
Feed Water Temperature	°C	104	105
Boiler Blowdown Rate	kg/h	250	381
Coal Feed Rate	kg/h	2210	1995
Limestone Feed Rate	kg/h	1019	1018
Combustion Air Flow	kg/h	21150	20740
Total Air Side Loss	mmH_2O	1455	1118
Total Gas Side Loss	mmH_2O	310	N/A
Particulate Emissions	$kg/10^6$k.cal.	0.216	Meets
SO_2 Emissions	$kg/10^6$k.cal.	2.52	Specification
No_x Emissions	$kg/10^6$k.cal.	2.16	
Stack Temperature	°C	176	163
Boiler Efficiency (ASME)	%	81.6	82.99
F.D. Fan H.P.		221	112
I.D. Fan H.P.		92.8	71
Excess Air	%	22	25.2

Bed Dimensions	F.W. Preferential	F.W. Secondary	D.B.-S
	1.23 m x 2.88 m	1.39 m x 2.88 m	2.74 m x 3.05 m
Operating Temperature	°C 885	830	885
Fluidizing Velocity	m/sec. 2.4	3.0	2.3
Excess Air	% 25	20	25
Ca/S Ratio	3:1	3:1	
Expanded Depth	m 1.37	1.37	0.9

Turndown Ratio	4.5:1 with preferential bed	4.54:1 using single zone

Table 7 - Comparative data on electrical requirements

Figures given for the Foster Wheeler design are based upon the contracted installation for two operating boilers.

Figures for the Dominion Bridge-Sulzer design are extrapolated to a two-boiler installation based upon their initial single boiler proposal.

System	Foster Wheeler Design H.P.		D.B.-S. Design H.P.	
	Connected Load	Maximum Motor	Connected Load	Maximum Motor
Coal Handling	85	20	160	25
Limestone Handling	71	15	184	25
Woodchip Handling	14	5	110	75
Boiler and Draft System	850	300	924	250
Oil Fuel and Water System	45	40	65	25
Ash Handling	195	50	160	75
Building Services	32	10	116	15
Compressors	50	25	300	150
TOTALS	1328		1909	
Nominal consumption for 2 boilers at M.C.R.	690 kW			
Emergency Diesel Generator	620 kW		500 kW	

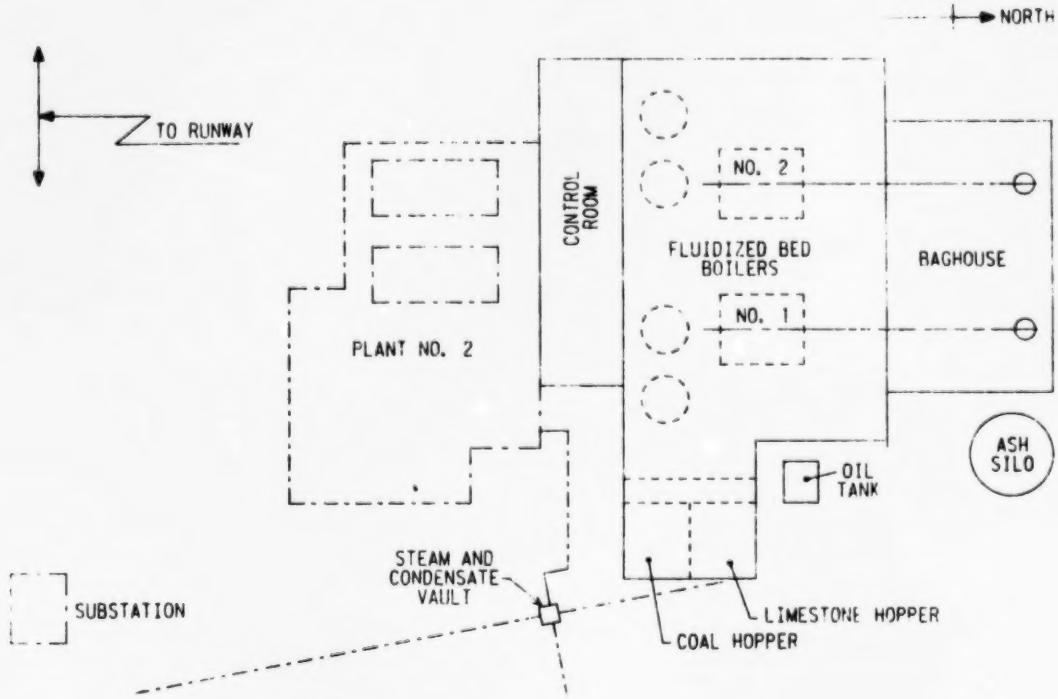


Fig. 1 - Site layout - **Foster Wheeler design**

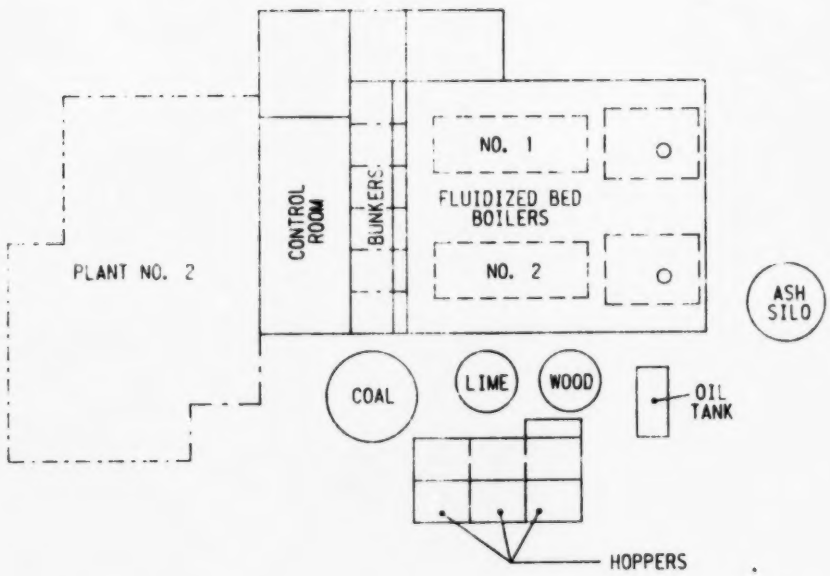


Fig. 2 - Site layout - **Dominion Bridge - Sulzer design**

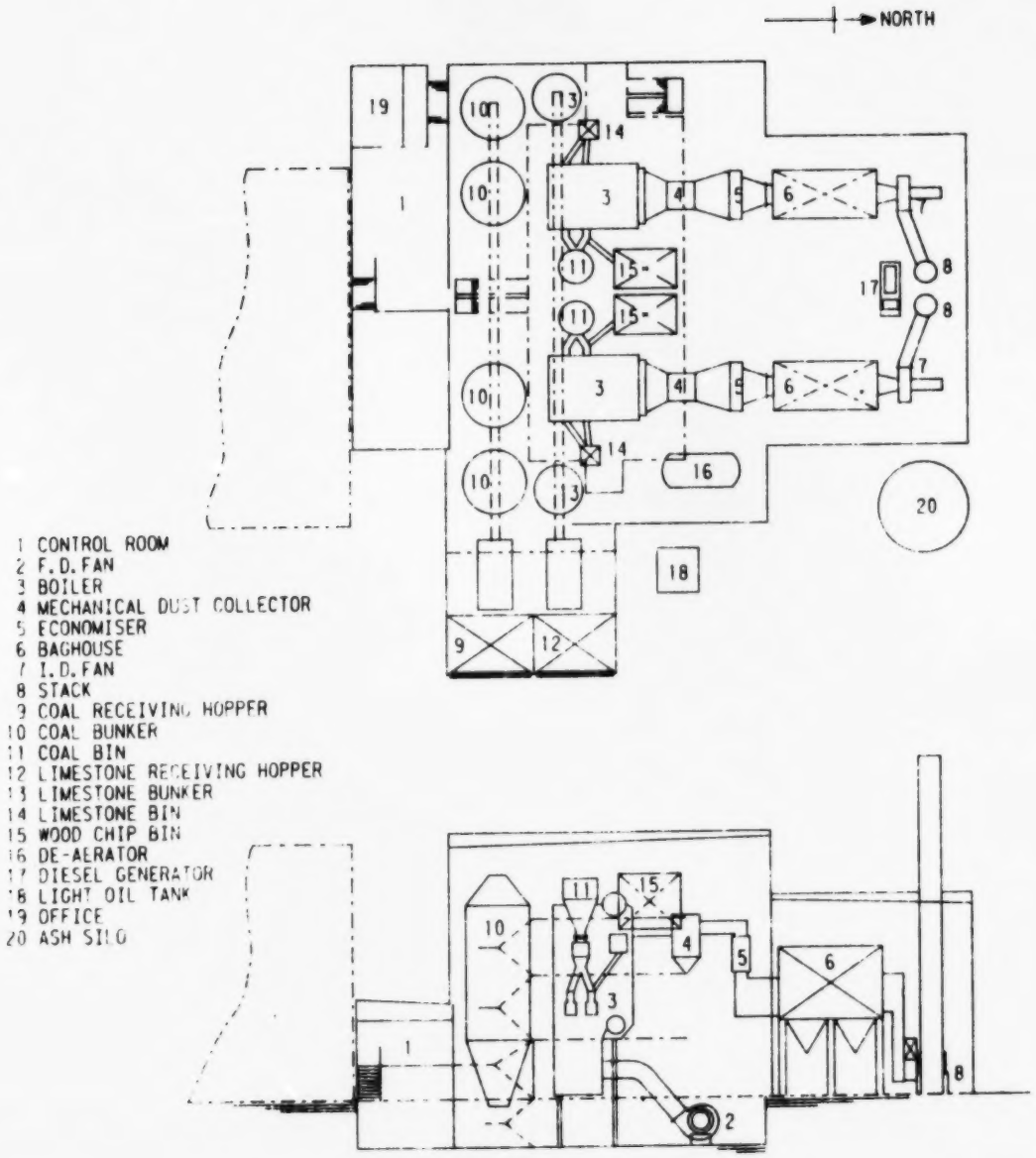
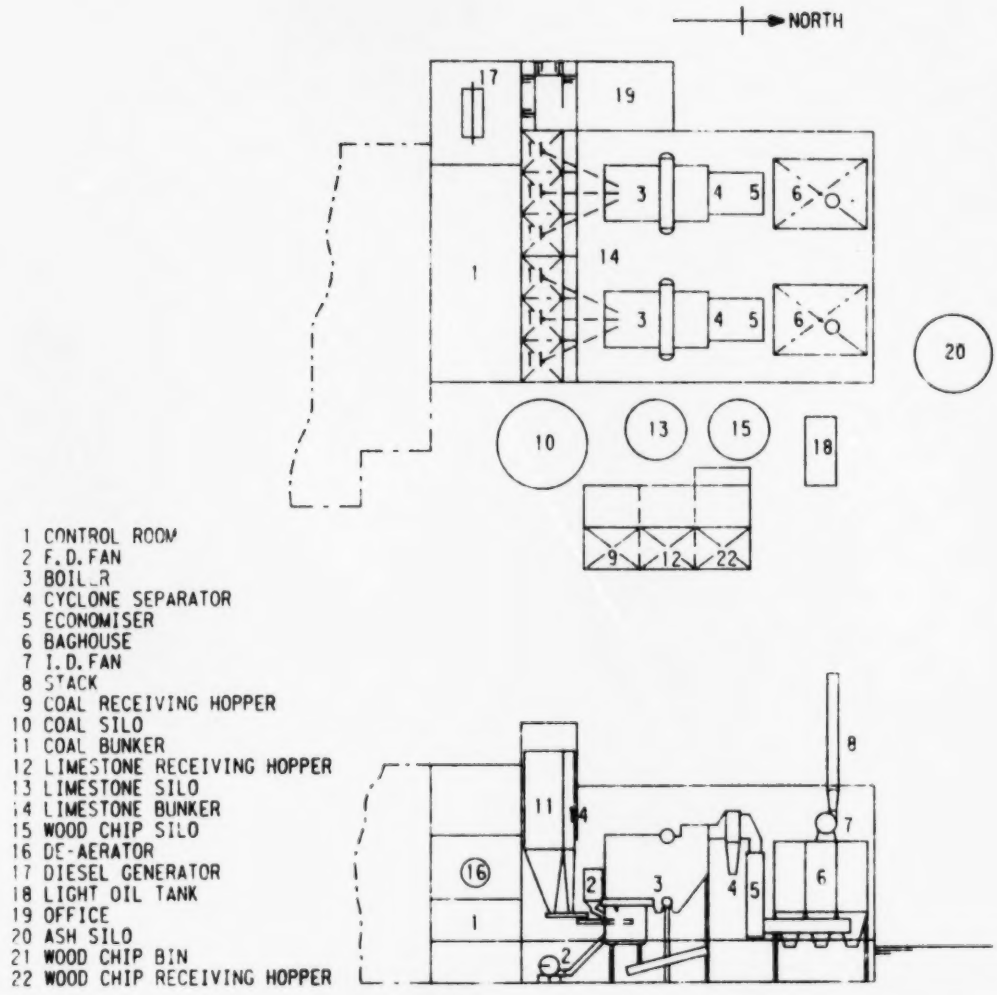
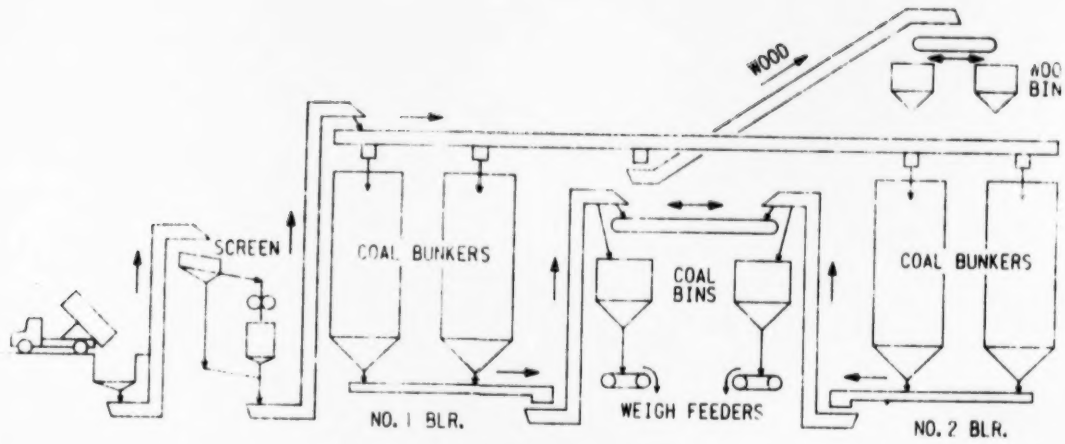


Fig. 3 - Plant layout - Foster Wheeler installation

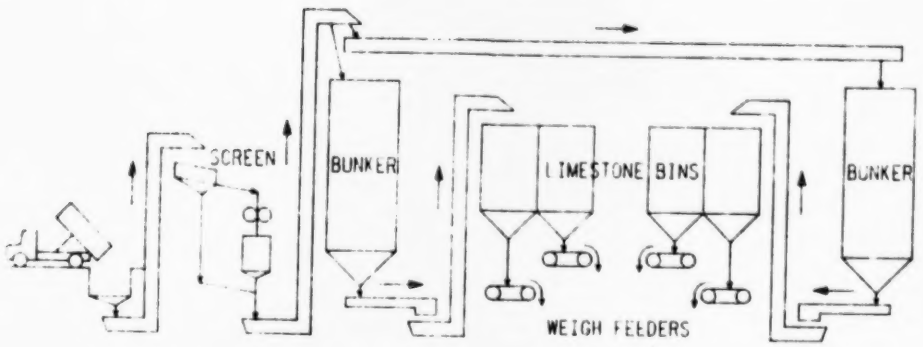


1 CONTROL ROOM
2 F.D. FAN
3 BOILER
4 CYCLONE SEPARATOR
5 ECONOMISER
6 BAGHOUSE
7 I.D. FAN
8 STACK
9 COAL RECEIVING HOPPER
10 COAL SILO
11 COAL BUNKER
12 LIMESTONE RECEIVING HOPPER
13 LIMESTONE SILO
14 LIMESTONE BUNKER
15 WOOD CHIP SILO
16 DE-AERATOR
17 DIESEL GENERATOR
18 LIGHT OIL TANK
19 OFFICE
20 ASH SILO
21 WOOD CHIP BIN
22 WOOD CHIP RECEIVING HOPPER

Fig. 4 - Plant layout - Dominion Bridge - Sulzer Design



Flow Diagram - Coal and Wood

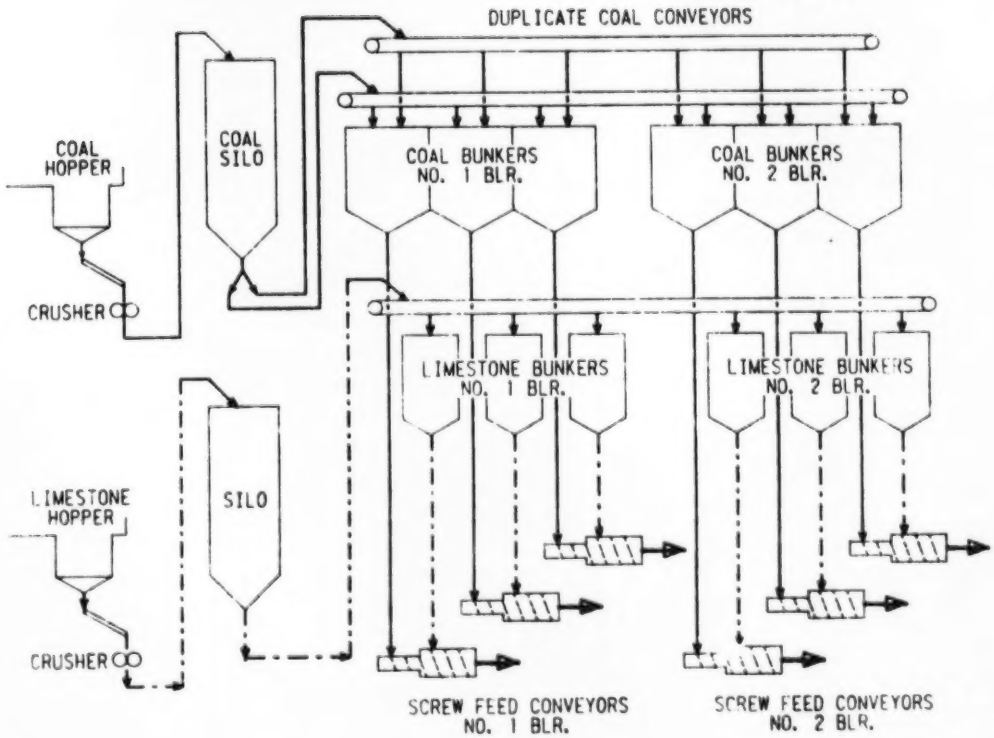


Flow Diagram - Limestone

MATERIALS HANDLING - RATES AND CAPACITIES

	COAL	LIMESTONE
Transfer receiving hoppers to bunkers	6.3 kg/s (25TPH)	6.3 kg/s (25TPH)
Bunkers - capacity	4 x 74.8 Mg (82.5 T)	2 x 68 Mg (75 T)
Transfer to Bins	1.3 kg/s (5 TPH)	0.63 kg/s (2.5TPH)
Bins - Capacity	2 x 4.5 Mg (5 T)	2 x 2.3 Mg (2.5 T)
Burn rate	0.65 kg/s (2.5TPH)	0.3 kg/s (1.13TPH)

Fig. 5 - Flow diagrams for coal, wood and limestone - Foster Wheeler installation



MATERIALS HANDLING - RATES AND CAPACITIES

	COAL	LIMESTONE
Transfer hopper to silo	8.8 kg/s (35TPH)	8.8 kg/s (35 TPH)
Silo-capacity	1 x 221 Mg (244 T)	1 x 130 Mg (144 T)
Transfer silo to bunkers	8.8 kg/s (35TPH) duplicated	8.8 kg/s (35TPH) single
Bunker - capacity	6 x 25 Mg (27.5 T)	6 x 14.5 Mg (16 T)

Fig. 6 - Flow diagrams for coal and limestone - Dominion Bridge - Sulzer Design

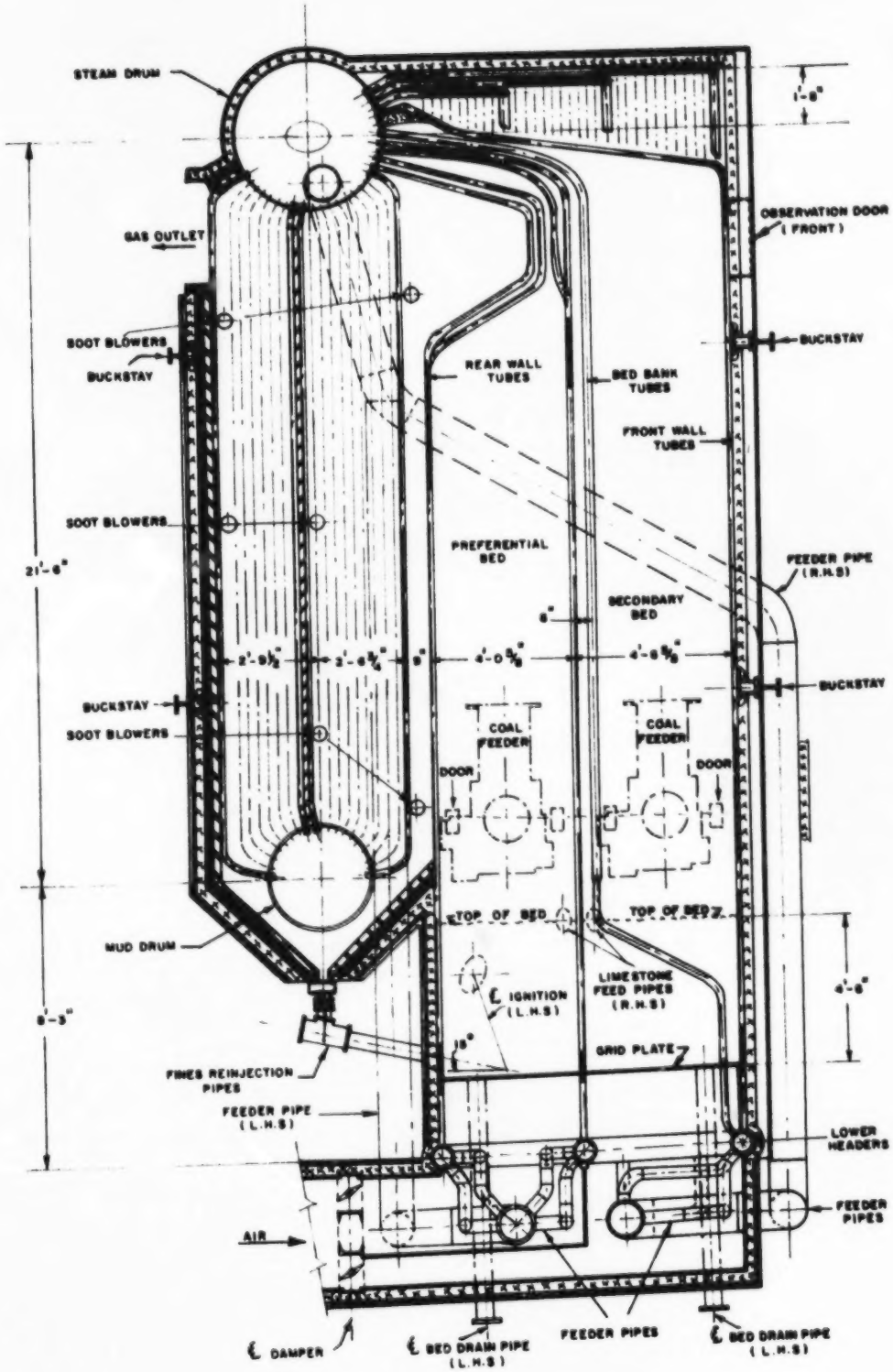


Fig. 7 - Sectional elevation - Foster Wheeler boiler

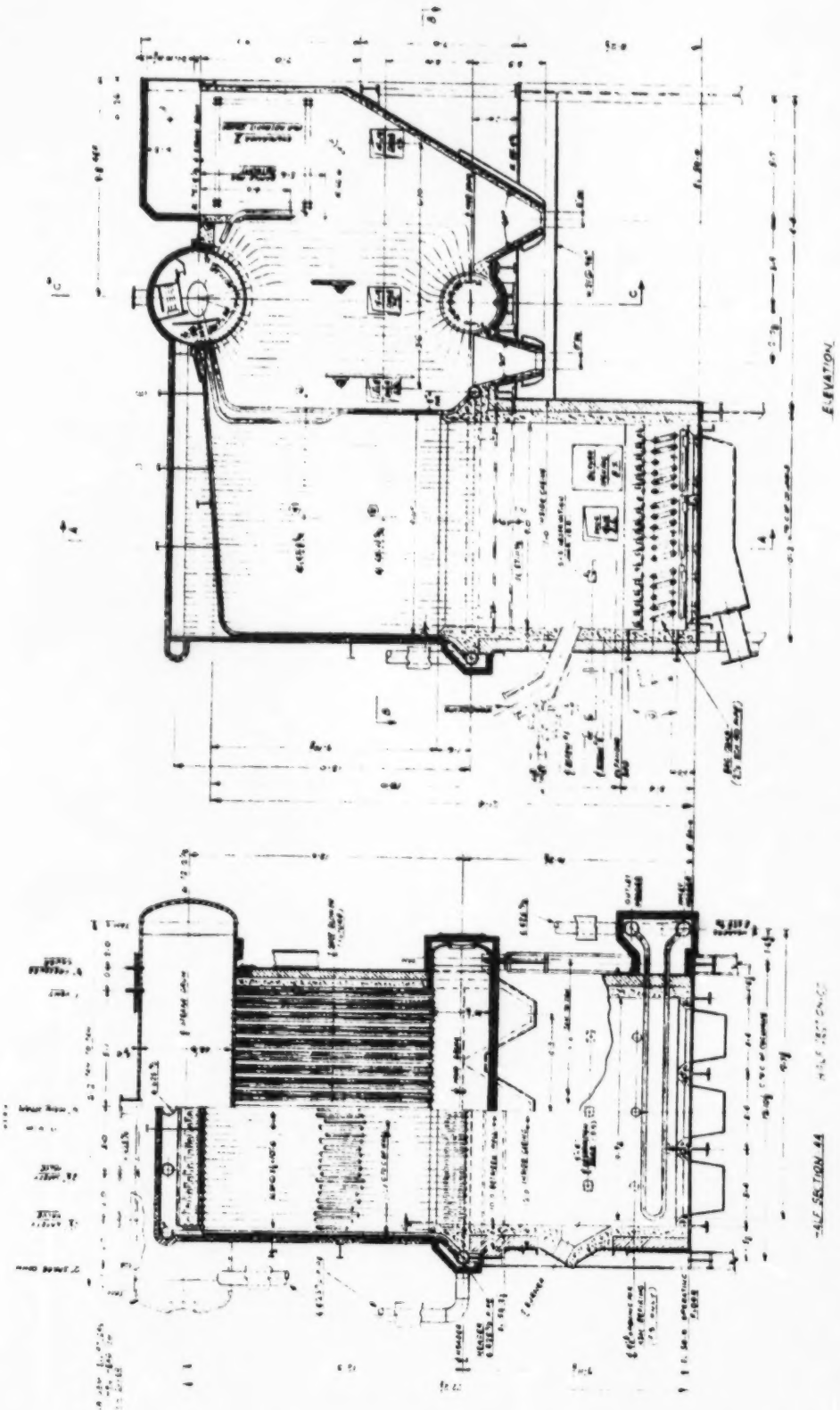


Fig. 8 - Sectional elevation - Dominion Bridge - Sulzer boiler

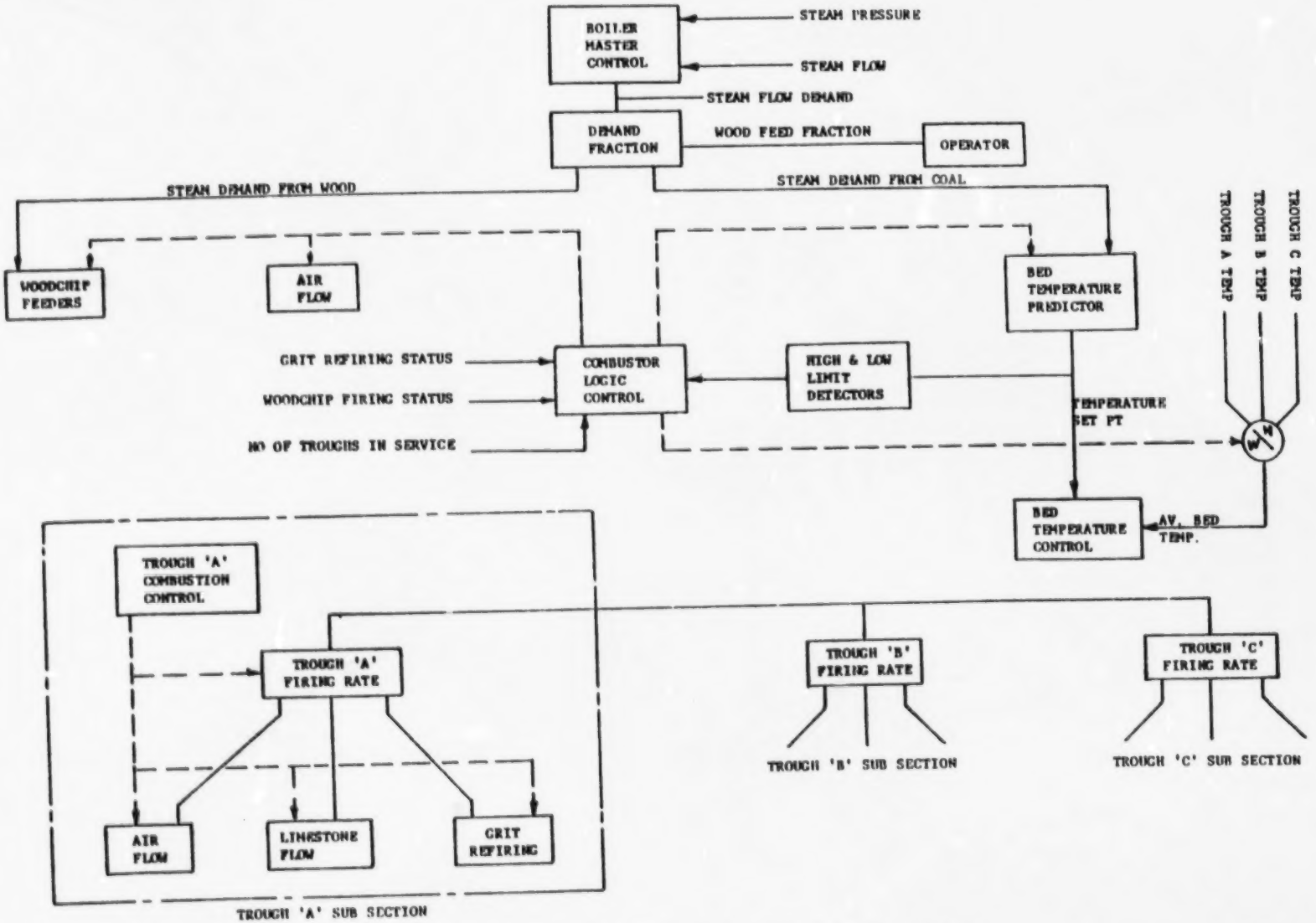


Fig. 9 - Schematic of Dominion Bridge - Sulzer combustor supervisory system

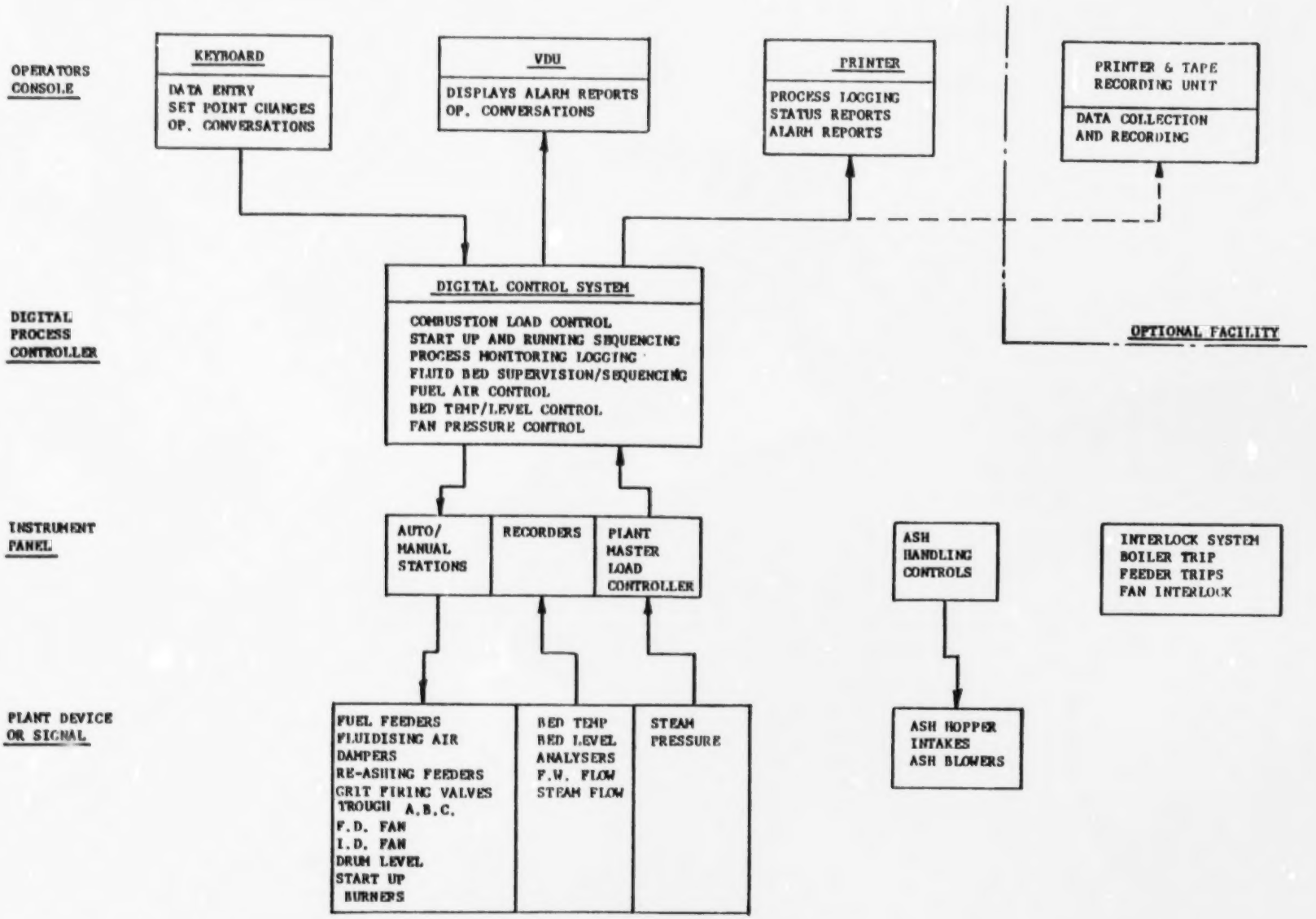


Fig. 10 - Schematic of Dominion Bridge - Sulzer combustor control system